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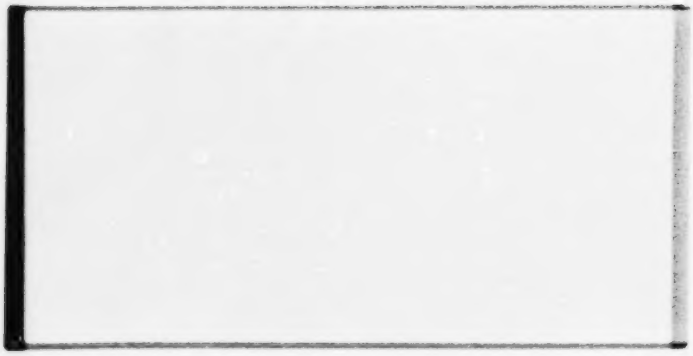

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RESIDENTIAL HEAT PUMP WATER HEATERS LABORATORY ASSESSMENT

Report No 83-127-K

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ABSTRACT

Test results of four residential heat pump water heaters under varying laboratory conditions are presented. Both energy savings and hot water delivery capability were assessed in comparison with a modern residential electric water heater. In addition to energy saving, other potential benefits are briefly discussed.

job	file	date	report no.
740612-129-111	814.33	March 28, 1983	83-127-K

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To Mr. F.J. Kee
Director of Research

RESIDENTIAL HEAT PUMP WATER HEATERS LABORATORY ASSESSMENT

INTRODUCTION

Domestic water heating represents one of the major costs in the homeowner's energy bill. General public awareness for energy saving and conservation coupled with increasing energy costs has placed new emphasis on the development of energy conserving devices. One such development is the heat pump water heater (HPWH).

It is claimed that under certain conditions HPWHs have the capability of reducing water heating costs up to 60% with the added benefits of dehumidifying, air conditioning and the option of using waste heat from various sources.

A heat pump water heater works primarily the same as a space heating heat pump using the mechanical work provided by an electrical motor to move heat from one location to another. Low grade heat is extracted from the surroundings, upgraded by a vapour compression cycle, and transferred to the water in a storage tank.

There are two distinct types of heat pump water heaters presently manufactured: "add-on" units and "integral" systems. The add-on units in which the compressor, evaporator and the refrigerant-to-water heat exchanger (condenser) are assembled in one casing are intended to be plumbed to the inlet and outlet of standard electric water heaters. The integral system has the compressor and evaporator mounted on top of a storage tank with the condenser immersed inside the tank. The storage tank of an integral system also includes two heating elements for back-up or straight resistance heating.

The purpose of this assessment was twofold:

. to examine the performance of four commercially-available residential-type heat pump water heaters,

. to investigate the economics of such systems with respect to oil, electric and gas-heated houses and the potential benefits from indoor dryer venting, exhaust air heat recovery, shared gas-electric water heating in gas-heated homes and indoor air dehumidification.

Of the four heat pump water heaters tested, three were of the "add-on" type (A,C,D) while the fourth was an integral system (B). Detailed technical specifications of the four units tested and four additional commercially-available systems are given in Appendix D.

In order to establish the thermal performance, the following tests were performed:

- "Delivery" test - in accordance with the Canadian Standards Association (CSA) standard C191 for electric storage tank water heaters/1/, and
- "Recovery Efficiency" test - following the recommendations in the Gas Appliance Manufacturers Association (GAMA) draft standard for heat pump water heaters/2/.

For purposes of performance comparison, similar tests were conducted on a 272 litre (60 gal) capacity "Energy Miser" electric water heater (EWH). This tank had two 3800 W heating elements and 75 mm (3") of fiberglass insulation. A detailed description of the test method, instrumentation and data reduction procedure is given in Appendix A.

RESULTS AND DISCUSSION

Comparative test results on hot water "delivery capability" for the four heat pump water heaters and the electric water heater are graphically illustrated in Figures 1 and 2. The results were obtained at a "delivery cycle average temperature" ($\bar{T}_{S1}$) of approximately 60°C at two different schedules of 227 and 454 litres/day respectively.

At a delivery schedule of 227 litres/day, three heat pump water heaters (A,B and C) were capable of supplying the required amount of hot water at average outlet temperatures comparable with those of the electric water heater. The average outlet temperatures of system D were substantially lower, but still acceptable (Figure 1).

At a delivery schedule of 454 litres/day only system A could supply hot water at outlet temperatures comparable with the electric water heater. Outlet temperatures as low as 42, 35 and 46°C were recorded for systems B, C and D respectively (Figure 2).

Summarized results for various average cycle temperatures are given in Tables B1 and B2 (Appendix B).

Very good delivery results were obtained when the integral system had the upper auxiliary element of the storage tank operational (Figure 3).

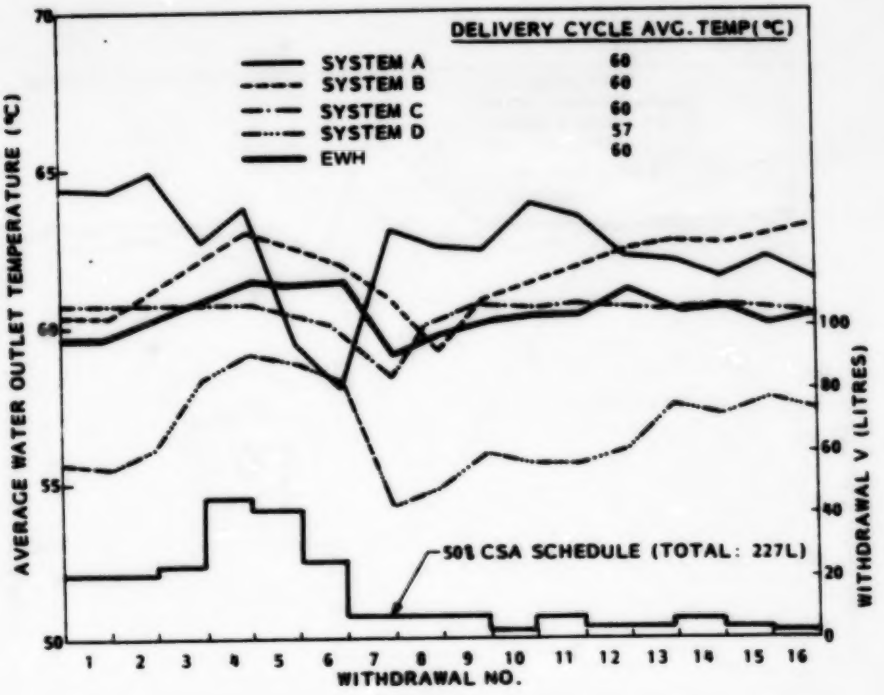

FIGURE 1

227 L - DELIVERY CAPABILITY TEST RESULTS

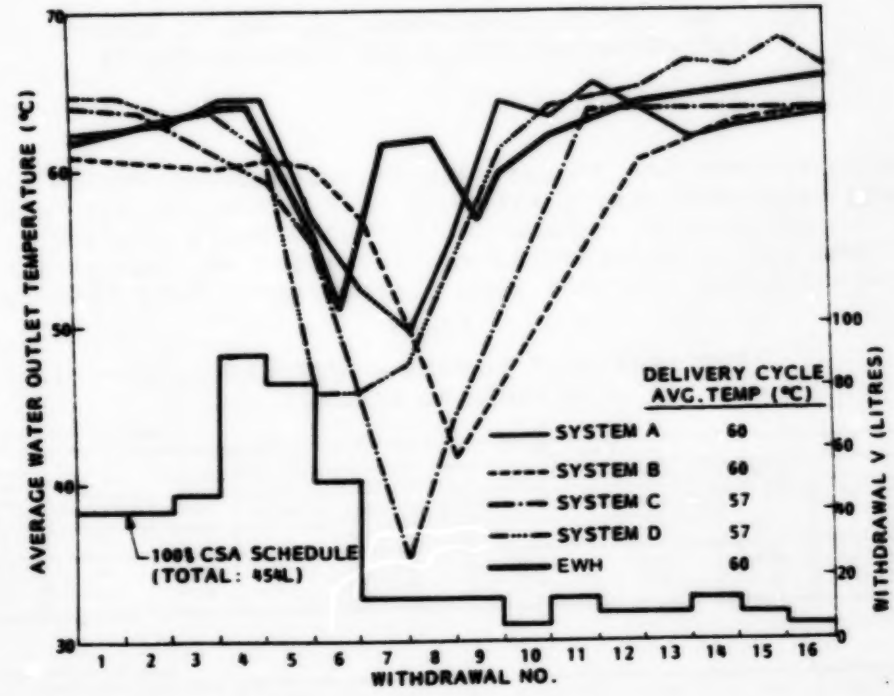

FIGURE 2

454 L - DELIVERY CAPABILITY TEST RESULTS

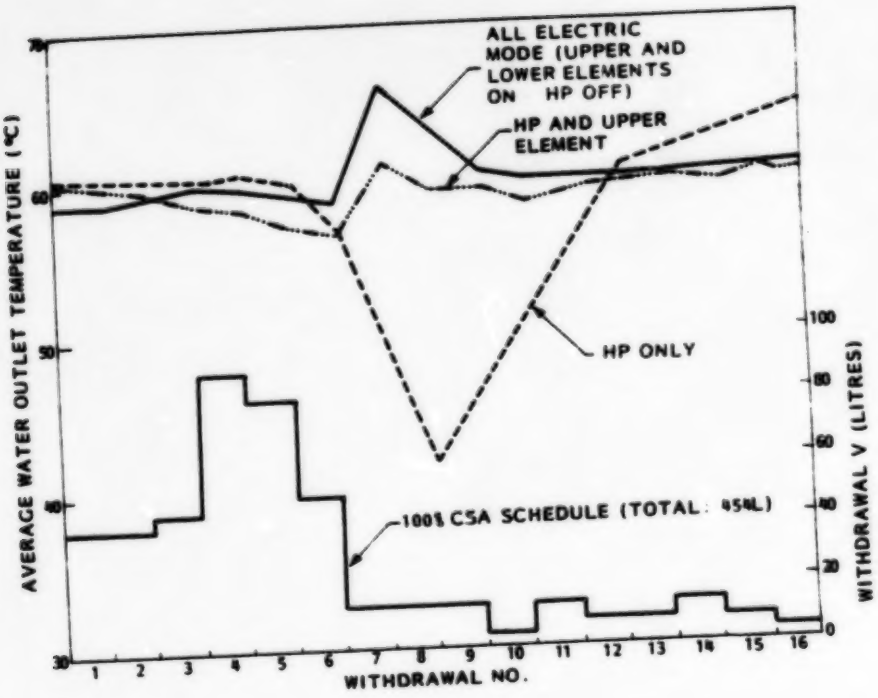

FIGURE 3

SYSTEM B: 454L - DELIVERY CAPABILITY TEST RESULTS
AT 60°C DELIVERY CYCLE AVERAGE TEMPERATURE

The HPWH's energy consumption, energy output and coefficients of performance (COP) in Table B3 - Appendix B (see sample of results in Table 1 below), along with the EWH energy consumption (Figure B1) formed the basis for the calculation of the energy savings of heat pump water heaters over electric water heaters.

TABLE 1

DELIVERY TEST - ENERGY FLOW ANALYSIS
(SAMPLE OF RESULTS)

227L (50 Gal) Daily Delivery Schedule

System	Average Water Inlet Temp ($\bar{T}_I$)	Delivery Cycle Avg Temp ($\bar{T}_{SI}$)	Adjusted Temp Span	One Tank System						
				Avg Daily Energy Consump		Avg Daily Energy Output		Avg Daily S.B. Losses	Average Net C.O.P.	Average Gross C.O.P.
				Actual ($\bar{E}_I$)	Temp Adj* ($\bar{E}_I'$)	Actual ($\bar{E}_{OI}$)	Temp Adj* ($\bar{E}_{OI}'$)			
	°C	°C	°C	kWh		kWh		kWh		
HP-A	15.5	60	10-60	7.73	8.30	12.12	13.00	2.46	1.57	1.87
	10.2	53	10-53	6.23	6.24	11.15	11.18	2.46	1.79	2.19

454L (100 Gal) Daily Delivery Schedule

HP-A	11.9	60	10-60	13.28	13.60	25.32	26.00	2.46	1.92	2.10
	9.3	53	10-53	10.97	10.92	22.46	22.36	2.46	2.05	2.27

* Estimated Values for Adjusted Temperature Span

The results of these computations are presented in Table 2.

TABLE 2

AVERAGE DAILY ENERGY SAVINGS OF HPWHs OVER EWHs

227L (50 Gal) Daily Delivery Schedule

System	Delivery Cycle Average Temp ($\bar{T}_{S1}$)	One Tank System Energy Savings (Temp Adjusted)**			
		1		2	
	°C	kWh	%	kWh	%
HP-A	60	6.20	42.8	5.90	40.7
	53	5.66	47.6	5.86	40.4
HP-B	60	5.85*	40.3*	5.06	34.9
HP-C	60	5.60	38.6	5.45	37.6
	63	5.30	33.8	4.19	28.9
	53	5.20	43.7	5.62	38.8
HP-D	57	6.63	49.5	6.37	43.9
	47	4.89	50.4	5.68	39.2

454L (100 Gal) Daily Delivery Schedule

HP-A	60	12.40	47.7	11.97	46.0
	53	11.68	51.7	10.83	41.7
HP-B	60	12.40*	47.7*	11.42	43.9
HP-B+UE	60	9.90*	38.1*	9.87	38.0
HP-C	57	11.30	46.1	10.68	41.1
	53	10.95	48.5	10.91	42.0
HP-D	57	12.97	52.9	12.19	46.9
	44	10.69	59.4	10.09	38.8

Note:

1 HP Connected to a 182L Capacity EWH ("Cascade 40") with Heating Elements Non-operational.

2 Estimated Values for HP Connected to a 272L Capacity EWH ("Energy Miser") with Upper Element (UE) Operational.

* Integral System: Storage Tank Capacity: 310L

** Temp Adjusted: Estimated Values for "Adjusted Temperature Span" (See Table 1).

Analysis of these results showed that significantly high energy savings were obtained when the units tested operated in the "heat pump mode" only in which the auxiliary heating elements of the storage tank were not operational. At a delivery average temperature of approximately 60°C energy savings up to about 50% (∿2400 kWh/A) and 53% (∿4700 kWh/A) were recorded depending on the heat pump unit and the size of the daily draw schedule - 227 and 454 litres respectively (column 1). However, it appears that this mode is not suitable for daily hot water usages in excess of 227 litres (see Figures 1 and 2).

The results in Figure 3 showed that for heavy users of hot water, the storage tank should always have the upper heating element operational. In this case it was estimated that under laboratory test conditions energy savings up to about 44% (∿2300 kWh/A) and 47% (∿4400 kWh/A) can be expected depending on the heat pump unit and the size of the daily draw schedule (Table 2 - column 2).

The results of the recovery efficiency ("heat-up") test revealed that the HPWHs tested required in some cases (HP-C) about twice as long to heat a tank of cold water than the EWH. Detailed results are graphically illustrated in Figures B2 and B3 - Appendix B. Calculations showed that the standard HPWHs have an average heating capacity in the range of 2.8 kW to 3.3 kW compared to 3.8 kW for the electric water heater. This lower heating capacity is reflected in the longer recovery time in the "heat-up" test as well as in some of the hot water outlet temperatures in the 454 litres daily schedule which did not always reach the desired output setting.

In addition to the projected energy savings previously discussed, several aspects related to other potential benefits derived from the installation of heat pump water heaters in residences were briefly examined (Appendix C).

As shown previously (Table 2), annual savings of up to 2300 kWh (227 litres/day) and 4400 kWh (454 litres/day) may be expected in certain conditions with the addition of a heat pump water heater to a standard electric water heater. When the effect on the heating load of a home was considered, the savings lowered to about 700 and 1500 kWh/A respectively (see Table C1 - Appendix C). When heat recovery from indoor dryer venting was considered, annual savings of 1450 and 2250 kWh were estimated. Air dehumidification and cooling are both felt to be additional benefits derived from the installation of heat pump water heaters in residences. However, it is difficult to attach a monetary value to these benefits for lack of any data base.

It is important to stress that the economical analysis presented in Appendix C is based on assumptions that have not, as yet, been verified in field trial situations. The usefulness of these projected benefits should be treated as indicative of possibilities or trends.

CONCLUSIONS

1. At a delivery schedule of 227 litres/day, three of the four units tested (A,B and C) were capable of supplying the required amount of hot water at average outlet temperatures comparable with those of a typical electric water heater. The average outlet temperatures of unit D were lower but still acceptable.

2. At a delivery schedule of 454 litres/day only system A could supply hot water at outlet temperatures comparable with the electric water heater.

3. Under laboratory test conditions annual energy savings up to 2400 kWh (∿50%) and 4700 kWh (∿53%) were estimated for HPWHs operating in "heat pump mode" only, depending on the unit tested, the hot water delivery temperature, and the size of the daily draw schedule - 227 and 454 litres respectively. However, the recovery efficiency of HPWHs operating in this mode was inferior to that of the EWH.

4. The recovery efficiency of HPWHs was considerably improved by activating the upper heating element of the storage tank. In this case the estimated annual energy savings were slightly reduced to about 2300 kWh (∿44%) and 4400 kWh (∿47%) depending on the HP unit, the hot water delivery temperature and the size of the daily draw schedule.

5. Net savings of about 700 kWh (227 litres/day) and 1500 kWh (454 litres/day) of the annual energy required for domestic water heating were estimated for heat pump water heating units installed in oil, electric or gas heated houses.

6. Greater savings may be achieved (approximately 1450 and 2250 kWh/A) in homes where indoor dryer venting and exhaust air heat recovery are considered.

7. Shared gas/heat pump water heating systems in gas heated homes were found not to have a promising potential for the time being.

8. The indoor air dehumidification may have a desirable effect on lowering the amount of condensation and moisture in the house as well as in reducing the electrical load in houses equipped with air conditioning systems. However, it is difficult to attach a monetary value to these benefits for lack of any data base.

9. It is recommended that further studies be conducted to establish the potential benefits from installation of HPWH systems in residential, commercial and industrial buildings.

ACKNOWLEDGEMENTS

The authors wish to express their thanks to Mr. J.P. Belaskie and Mr. E.A. Thompson for their contribution in the preparation of this report.

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3. Bell, J.M. 1977. Domestic Hot Water Tank Heat Loss: Standby vs CSA Usage Pattern, Ontario Hydro Memorandum, File 814.33.

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APPENDIX A

TEST METHOD, INSTRUMENTATION AND DATA REDUCTION PROCEDURE

In order to obtain an energy baseline for the total energy required to supply a certain amount of hot water at a desired temperature, a "two-tank system" test procedure was used. The schematic diagrams of the experimental installation for the add-on units and the integral system are illustrated in Figures A1 and A2.

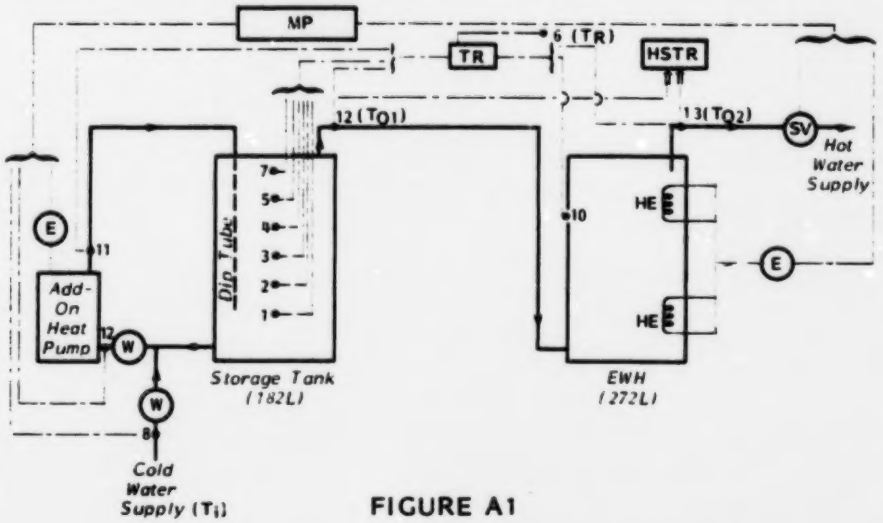

FIGURE A1

EXPERIMENTAL INSTALLATION - SCHEMATIC
"ADD-ON" HEAT PUMP WATER HEATER

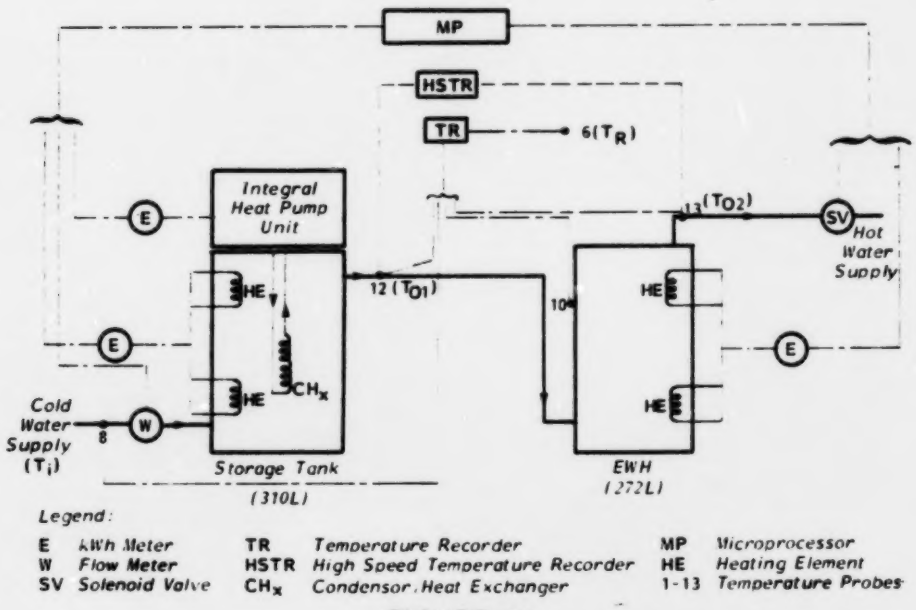

FIGURE A2

EXPERIMENTAL INSTALLATON - SCHEMATIC
INTEGRAL HEAT PUMP WATER HEATER

The storage tank in Figure A1 was a standard "Cascade 40" EWH with the heating elements non-operational. The storage tank in Figure A2 was the original tank of the integral system in which the heating elements were connected to the electric power supply and activated only during the performance of specific tests in one tank system (ie: HP + Upper Element (UE): ON, Bottom Element (BE): OFF or All Electric Mode (AEM): UE + BE: ON, HP: OFF). The second tank was in both cases a 272 litres "Energy Miser" EWH with both heating elements operational.

In addition to creating the energy baseline as mentioned above, the two-tank system procedure offered the advantage of gathering, at the same time, all the experimental data necessary to perform the energy flow analysis for each of the basic operational modes: HP Mode only, HP + Upper Element ON and All Electric Mode. It should be mentioned that the results on the two-tank system may be of great interest for load management purposes.

The delivery tests were conducted at specific hot water delivery temperatures for each heat pump water heater unit (see Tables B1 and B2 - Appendix B) and at 60°C thermostat setting of the electric water heater. Tests were run at two different daily water consumptions of 227 and 454 litres respectively using the same demand pattern as required by CSA standard C191 (Table A1).

The delivery schedule (Table A1) was implemented by a microprocessor based controller which also kept performance records of energy consumption and water flow. Temperatures throughout the test system were recorded on two strip chart recorders. The actual water inlet and outlet temperatures in Tables A2 to A5 were averaged daily according to a weighting dependent on the draw sizes. The temperatures of the water being withdrawn from the heat pump water heater ($\bar{T}_{o1}$), in Tables B1 and B2 - Appendix B, are the weighted averages of recorded data over three to five days. Due to the difficulty in accurately establishing the same delivery cycle average temperature ($\bar{T}_{s1}$) for each heat pump water heater and due to the fluctuations in the inlet and outlet water temperatures, the energy consumption was linearly adjusted for a desired temperature rise (adjusted temperature span) usually 10 to 60°C as shown in Tables A2 to A5. It should be mentioned that in most of the cases, the actual measured temperatures were close to the desired values and consequently the energy adjustments were fractionally small.

The "Recovery Efficiency" test consisted of measuring the energy and time required for the heat pump to heat a cold tank of water at the same initial temperature ($\sim$10°C) up to an average tank temperature of approximately 60°C.

For purposes of comparison, similar tests were performed separately on the 272 litres capacity electric water heater at different thermostat settings and the two water draw schedules mentioned above. Detailed results of these measurements are given in Appendix B.

TABLE A1

DELIVERY SCHEDULES

Withdrawal Number	Time	Withdrawl - Litres*	
		1	2
1	7:00	20.0	40.0
2	8:00	20.0	40.0
3	9:00	23.0	46.0
4	10:00	45.0	90.0
5	10:30	41.0	81.0
6	11:00	25.0	50.0
7	12:00	7.0	14.0
8	13:00	7.0	14.0
9	14:00	7.0	14.0
10	15:00	3.0	5.0
11	16:00	7.0	14.0
12	17:00	4.0	9.0
13	18:00	4.0	9.0
14	19:00	7.0	14.0
15	20:00	4.0	9.0
16	21:00	3.0	5.0
Daily Total (Litres)		227.0	454.0

* 1 - 50% CSA Schedule (Ontario Hydro schedule for residential SDHW systems)

2 - CSA schedule for residential EWHs

TABLE A2

HP-A DAILY DELIVERY TEST RESULTS

	One Tank System						Two Tank System			
Date	Average Ambient Temp	Average Inlet Temp	Weighted Avg Outlet Temp	Lowest Outlet Temp	Electrical Energy Consump (Measured)	Energy Adjusting Factor*	Weighted Avg Outlet Temp	Lowest Outlet Temp	Electrical Energy Consump (Measured)	Energy Adjusting Factor*
	°C	°C	°C	°C	kWh		°C	°C	kWh	
Jul 31	21.4	12.6	61.2	52.8	13.84	0.285	59.5	55.2	14.56	0.310
Aug 1	20.3	12.3	60.5	49.7	12.10	0.251	59.0	55.0	12.96	0.278
Aug 2	20.4	11.4	59.9	49.2	13.50	0.278	58.7	57.0	15.16	0.321
Aug 3	21.1	11.4	60.7	49.2	13.38	0.271	59.5	57.8	14.84	0.309
Avg Over Test Period	$\bar{T}_R$ = 20.8	$\bar{T}_i$ = 11.9	$\bar{T}_{01}$ = 60.6	$\bar{T}_{01min}$ = 50.2	$\bar{E}_1$ = 13.21	0.271	$\bar{T}_{02}$ = 59.2	$\bar{T}_{02min}$ = 56.3	$\bar{E}_2$ = 14.38	0.305

Delivery Schedule: 454L (100 Gal) Delivery Cycle Average Temperature $\bar{T}_{S1} \cong 60°C$

Adjusted Daily Energy Consumption* (10°-60° Adjusted Temp Span) — HP Only $\bar{E}_1' = 13.55$ kWh; 2 Tank System $\bar{E}_2' = 15.25$ kWh

TABLE A3

HP-D DAILY DELIVERY TEST RESULTS

	One Tank System						Two Tank System			
Date	Average Ambient Temp	Average Inlet Temp	Weighted Avg Outlet Temp	Lowest Outlet Temp	Electrical Energy Consump (Measured)	Energy Adjusting Factor*	Weighted Avg Outlet Temp	Lowest Outlet Temp	Electrical Energy Consump (Measured)	Energy Adjusting Factor*
	°C	°C	°C	°C	kWh		°C	°C	kWh	
Oct 7	21.7	15.0	57.1	53.2	6.4	0.152	57.3	55.3	7.86	0.186
Oct 8	21.1	15.1	57.4	55.1	5.8	0.137	57.1	55.7	7.80	0.186
Oct 9	20.8	15.1	60.2	53.6	6.4	0.142	57.7	57.0	7.64	0.179
Oct 10	20.8	15.2	57.7	53.2	6.8	0.160	57.5	55.7	8.68	0.205
Oct 11	20.7	15.1	55.5	53.1	5.2	0.129	57.0	54.1	7.74	0.185
Avg Over Test Period	$\bar{T}_R$ = 21.0	$\bar{T}_i$ = 15.1	$\bar{T}_{01}$ = 57.6	$\bar{T}_{01min}$ = 53.6	$\bar{E}_1$ = 6.12	0.144	$\bar{T}_{02}$ = 57.3	$\bar{T}_{02min}$ = 55.6	$\bar{E}_2$ = 7.94	0.188

Delivery Schedule: 227L (50 Gal) Delivery Cycle Average Temperature $\bar{T}_{S1} \cong 57°C$

Adjusted Daily Energy Consumption* (10° - 57°C Adjusted Temp Span) — HP Only $\bar{E}_1' = 6.77$ kWh; 2 Tank System $\bar{E}_2' = 9.41$ kWh

*Method Of Adjusting Daily Energy Consumption For Adjusted Temp Span

$$C.O.P. = \frac{mCp\,\Delta T_{Actual}}{E_{Meas}} = \frac{mCp\,\Delta T_{Adjusted\ Temp\ Span}}{E_{Adjusted}} \longrightarrow E_{Adjusted} = \frac{E_{Meas}\,\Delta T_{Adjusted\ Temp\ Span}}{\Delta T_{Actual}}$$

If $\frac{E_{Meas}}{\Delta T_{Actual}}$ = Energy Adjusting Factor Then Adjusted Daily Energy Consumption = [Energy Adjusting Factor] X [Adjusted Temp Span]

One Tank System: HP + ST
Two Tank System: HP + ST + EWH

TABLE A4

EWH DAILY DELIVERY TEST RESULTS

Date	Average Ambient Temp	Average Inlet Temp	Weighted Avg Outlet Temp	Lowest Outlet Temp	Electrical Energy Consump (Measured)	Energy Adjusting Factor
	°C	°C	°C	°C	kWh	
Jul 24	21.3	10.1	49.2	43.0	20.02	0.516
Jul 25	21.8	11.0	49.1	42.5	20.12	0.528
Jul 26	20.4	9.6	49.7	43.4	20.2	0.504
Jul 27	21.4	9.4	49.3	42.5	20.24	0.507
Avg Over Test Period	$\bar{T}_R$=21.3	$\bar{T}_i$=10.1	$\bar{T}_{O1}$=49.3	$\bar{T}_{O1min}$=42.9	$\bar{E}_1$=20.15	0.514

Delivery Schedule: 454L (100 gal) Delivery cycle average temperature $T_{S1} \simeq 53°C$
Adjusted daily energy consumption (10°-53°C Adj Temp Span): $\bar{E}_1$ = 22-10 kWh

TABLE A5

EWH DAILY DELIVERY TEST RESULTS

Date	Average Ambient Temp	Average Inlet Temp	Weighted Avg Outlet Temp	Lowest Outlet Temp	Electrical Energy Consump (measured)	Energy Adjusting Factor
	°C	°C	°C	°C	kWh	
May 8	21.4	11.0	60.7	60.0	14.32	0.289
May 9	21.0	11.7	60.6	59.8	14.34	0.293
May 10	21.4	9.9	60.9	59.3	14.98	0.294
May 11	21.8	8.0	60.7	59.5	15.3	0.289
May 12	21.5	8.1	61.1	59.7	15.34	0.289
Avg Over Test Period	$\bar{T}_R$=21.4	$\bar{T}_i$=9.7	$\bar{T}_{O1}$=60.8	$\bar{T}_{O1min}$=59.7	$\bar{E}_1$=14.86	0.291

Delivery schedule: 227L (50 gal) Delivery cycle average temperature $\bar{T}_{S1} \simeq 60°C$
Adjusted daily energy consumption (10°-60°C Adj Temp Span): $\bar{E}_1$ = 14.55 kWh

APPENDIX B

TEST RESULTS AND DISCUSSION

Tables B1 to B3 summarize the delivery test results for the four HPWHs tested and the electric water heater ("energy miser"). The heat pump water heater units were tested in two operational modes: "Heat pump operating mode" only (one tank system: Heat Pump (HP) + Storage Tank (ST) with no electrical back-up) and "Heat Pump + Electric Mode" (two tank system: HP + ST + EWH). Whereas the results in Tables B1 and B2 emphasize the delivery water temperatures the results in Table B3 are related to the system energy flow analysis. The energy savings of HPWHs over a standard EWH (Table 2) were calculated using the results in Table B3 and Figure B1. For load management purposes the energy savings in the two tank system were calculated and presented in Table B4.

Data for the recovery efficiency ("heat-up") test are graphically illustrated in Figures B2 and B3. Figure B2 shows the variation of the coefficient of performance with the average water temperature in the storage tank. The results show that units B, C and D behaved fairly similar in response to heating up a cold tank of water. Since these units had a constant flow water pump, their highest performance was achieved at the beginning of the experiment when the average water tank temperature had the lowest value and the temperature difference of the circulated water across the heat pump reached its maximum. Since the electrical energy input was fairly constant, per unit time interval, the decreasing temperature difference as the tank warmed up led to a decreasing COP value.

The plot for data obtained for unit A was somewhat unique. This unit was equipped with a thermostatic modulating valve which controlled the water flow and maintained a minimum outlet temperature of about 46°C for rapid recovery. Thus, with a constant outlet temperature from the heat pump water heater and a flow rate that varied almost proportionally with the inlet temperature, the COP value remained constant until the average water tank temperature reached approximately 36°C. At this point, the temperature difference between inlet and outlet started to fall and with a constant energy consumption per unit time interval the COP value started to drop off.

Recovery time versus the average water tank temperature is graphically illustrated in Figure B3. Since the integral unit had a 310 L tank, larger than the tank used with the add-on HPWHs, the estimated recovery curve for the integral unit with a 182 L storage tank capacity was also represented. For comparison purposes, a summary of energy consumption and heat-up time for a standard temperature interval of 10 to 60°C (adjusted temperature span) is given in Table B5. The results showed that the recovery time of the electric water heater was shorter than for any of the heat pump water heating systems (when tested in the heat pump mode). Consequently, the energy consumption over the period was higher.

Using the data from Table B5 and average COP values from Figure B2 the heating capacity of HPWHs was calculated within a range of 2.8 kW to 3.3 kW which is less than the 3.8 kW rating of the electric water heater auxiliary elements (see also Appendix D).

TABLE B1

DELIVERY CAPABILITY TEST RESULTS
DAILY TOTAL: 227L (50 GAL)

System	Average Water Inlet Temp $\bar{T}_i$(°C)	One Tank System				Two Tank System				Average Ambient Air Temp $\bar{T}_R$(°C)
		Delivery Cycle Avg Temp $\bar{T}_{S1}$ (°C)	Average Water Outlet Temp $\bar{T}_{O1}$ (°C)	Lowest Outlet Avg Temp $\bar{T}_{O1min}$(°C)	Avg Daily Energy Consumption $\bar{E}_1$ (kWh)	EWH Thermostat Setting $\bar{T}_{S2}$ (°C)	Average Water Outlet Temp $\bar{T}_{O2}$ (°C)	Average Outlet Avg Temp $\bar{T}_{O2min}$(°C)	Avg Daily Energy Consumption $\bar{E}_2$ (kWh)	
HP-A	15.5 10.2	60 53	62.1 53.1	58.0 51.7	7.73 6.23	60 60	57.4 61.4	56.2 60.2	8.34 10.25	21.1 22.2
HP-B*	11.9	60	61.9	59.2	8.67	60	58.1	56.3	10.00	21.2
HP-C	10.3 14.4 10.1	60 63 53	60.4 63.1 53.2	58.3 60.8 50.4	8.90 9.60 6.67	60 60 60	56.6 58.5 58.4	55.1 57.3 57.3	9.68 10.51 9.93	21.7 21.1 21.6
HP-D	15.1 12.3	57 47	57.6 46.7	53.6 46.0	6.12 4.47	60 60	57.3 59.4	55.6 58.3	7.94 9.64	21.0 22.7
EWH	9.7 9.8	60** 45**	60.8 45.2	59.7 44.6	14.86 8.90					21.4 21.9

Legend:

HP: Heat Pump
ST: "Cascade 40" Storage Tank (Heating Elements Non-operational)
EWH: "Energy Miser 60" Electric Water Heater (Heating Elements Operational)
One Tank System: HP + ST
Two Tank System: HP + ST + EWH
* Integral System - Storage Tank Capacity: 310L
** EWH Thermostat Setting

TABLE B2

DELIVERY CAPABILITY TEST RESULTS
DAILY TOTAL: 454 L (100 GAL)

System	Average Water Inlet Temp $\bar{T}_i$ (°C)	One Tank System				Two Tank System				Average Ambient Air Temp $\bar{T}_R$ (°C)
		Delivery Cycle Avg Temp $\bar{T}_{S1}$ (°C)	Average Water Outlet Temp $\bar{T}_{O1}$ (°C)	Lowest Outlet Avg Temp $\bar{T}_{O1min}$ (°C)	Avg Daily Energy Consumption $\bar{E}_1$ (kWh)	EWH Thermostat Setting T_{S2} (°C)	Average Water Outlet Temp $\bar{T}_{O2}$ (°C)	Lowest Outlet Avg Temp $\bar{T}_{O2min}$ (°C)	Avg. Daily Energy Consumption $\bar{E}_2$ (kWh)	
HP A	11.9 9.3	60 53	60.6 52.5	50.2 36.9	13.21 10.97	60 60	59.2 60.2	56.3 59.1	14.38 16.81	20.8 20.8
HP B*	13.0	60	58.8	42.0	12.42	60	58.8	57.9	14.53	21.8
HP C	9.2 8.9	57 53	55.9 54.3	33.4 33.1	13.07 12.30	60 60	57.8 58.1	56.1 57.2	16.17 16.10	22.3 22.4
HP D	13.7 10.2	57 44	56.5 43.7	38.3 30.3	10.60 7.20	60 60	59.2 59.7	56.7 59.1	13.65 17.17	20.7 19.6
HP B* ADDITIONAL TESTS										
HP+UE	9.9	60	58.7	56.7	15.71	60	59.2	56.9	17.26	22.0
AEM	11.4	60	59.9	58.5	26.11					22.4
EWH	13.2 10.1 16.4	60** 53** 44**	59.3 49.3 43.6	46.7 42.9 37.6	24.25 20.15 14.46					22.1 21.3 20.0

LEGEND:

HP: Heat Pump
ST: "Cascade 40" Storage Tank (Heating Elements Non-operational)
EWH: "Energy Miser 60" Electric Water Heater (Heating Elements Operational)
UE: Upper Element of HP B Storage Tank
AEM: HP B All Electric Mode (ST Upper and Bottom Elements ON, HP-OFF)
One Tank System: HP + ST
Two Tank System: HP + ST + EWH
* Integral System - Storage Tank Capacity: 310L
** EWH - Thermostat Setting

TABLE B3
DELIVERY TEST-ENERGY FLOW ANALYSIS

System	Average Water Inlet Temp (T_I)	Delivery Cycle Avg Temp (T_{SI})	Adjusted Temp Span	One Tank System							Two Tank System								
				Avg. Daily Energy Cons		Avg. Daily Energy Output		Avg Daily S.B. Losses L*	Average Net C.O.P.	Average Gross C.O.P.	EWH Thermostat Setting (T_{SI})	Adjusted Temp Span	Avg Daily Energy Cons		Avg Daily Energy Output		Avg Daily S.B. Losses L**	Average Net C.O.P.	Average Gross C.O.P.
				Actual (E_I)	Temp Adj* (E'_I)	Actual (E_{OI})	Temp Adj* (E'_{OI})						Actual (E_I)	Temp Adj* (E'_I)	Actual (E_{OI})	Temp Adj* (E'_{OI})			
	°C	°C	°C	kWh		kWh		kWh			°C	°C	kWh		kWh		kWh		
HP A	15.5	60	10 60	7.76	8.60	12.32	13.60	2.46	1.57	1.87	60	10 60	8.36	9.95	10.69	11.0	4.62	1.31	1.82
	10.2	51	10 51	6.23	6.29	11.15	11.36	2.46	1.79	2.19	60	10 60	10.25	10.85	11.0		4.62	1.58	1.75
HP B	10.9	60	10 60	8.67	8.65	13.00	13.00	3.56	1.50	1.91	60	10 60	10.08	10.85	12.01	11.0	5.72	1.49	[illegible]
HP C	10.4	60	10 60	8.90	8.90	13.03	13.09	2.46	1.46	1.74	60	10 60	9.68	10.50	12.09	11.0	4.62	1.76	1.76
	10.9	65	10 65	9.60	10.00	12.60	14.78	2.46	1.33	1.57	60	10 60	10.50	11.95	13.67	11.0	4.62	1.89	1.50
	10.1	56	10 56	6.70	6.70	11.23	11.18	2.46	1.67	2.04	60	10 60	9.91	10.60	12.56	11.0	4.62	1.23	1.76
HP D	15.1	57	10 57	6.82	6.72	11.05	12.22	2.46	1.61	2.19	60	10 60	7.94	9.41	10.97	11.0	4.62	1.38	1.92
	12.1	62	10 62	9.92	8.80	8.99	9.62	2.46	2.00	2.55	60	10 60	9.64	10.23	12.22	11.0	4.62	1.27	1.76

Daily Total Hot Water Use

HP A	10.9	60	10 60	16.73	14.60	25.32	26.09	2.46	1.92	2.16	60	10 60	14.38	15.25	26.60	26.0	4.62	1.73	2.02
	9.1	56	10 56	10.97	10.92	22.46	22.36	2.46	2.05	2.27	60	10 60	16.81	16.50	26.67	26.0	4.62	1.58	1.85
HP B	11.0	60	10 60	17.47	15.60	23.82	26.00	3.56	1.92	2.19	60	10 60	14.56	15.60	23.82	26.0	5.72	1.64	2.02
HP B-HE	9.9	60	10 60	15.73	16.10	25.18	26.00	3.56	1.62	1.84	60	10 60	17.26	17.50	25.18	26.0	5.72	1.48	1.80
HP A	9.2	57	10 57	15.07	13.70	24.28	24.44	2.46	1.85	2.09	60	10 60	16.17	16.65	25.29	26.0	4.62	1.56	1.85
	8.9	56	10 56	12.89	13.65	23.68	22.36	2.46	1.92	2.32	60	10 60	16.10	16.40	25.58	26.0	4.62	1.68	1.88
HP D	11.1	57	10 57	10.60	11.56	22.26	24.44	2.46	2.11	2.61	60	10 60	15.65	15.60	25.66	26.0	4.62	1.73	2.07
	10.2	49	10 49	7.70	7.10	17.92	17.68	2.46	2.42	2.76	60	10 60	11.37	11.80	25.74	26.0	4.62	1.50	1.72

Average Daily Energy Output — Actual: E_{OI} = output(off)$_{Actual}$; Temp Adj: E'_{OI} = Output(off)$_{Adj\ Temp\ Span}$

Average C.O.P. — Net: Average Daily Energy Output / Average Daily Energy Consumption; Gross: (Average Daily Energy Output − Average Daily Stand By Losses**) / Average Daily Energy Consumption

One Tank System: HP ST

Two Tank System: HP ST - EWH

* Temp Adjusted — Estimated Values for Adjusted Temperature Span

** See Measured S.B. Loss Values in Table B6

TABLE B4

AVERAGE DAILY ENERGY SAVINGS OF HPWHs OVER EWHs (TWO TANK SYSTEM)

System	Energy Savings (Temp Adjusted)**			
	227L/Day		454L/Day	
	kWh	%	kWh	%
HP-A	4.55	31.4	10.75	41.3
HP-B*	3.65	25.2	10.20	39.2
HP-B+UE*	-	-	8.50	32.7
HP-C	4.00	27.6	9.35	36.0
HP-D	5.09	35.1	11.00	42.3

Note:

EWH Thermostat Setting: 60°C
Delivery Cycle Avg Temp: 60°C

* Integral System: Storage Tank Capacity: 310L
** Temp Adjusted: Estimated Values for Adjusted Temperature Span 10-60°C

TABLE B5

RECOVERY EFFICIENCY TEST RESULTS

SUMMARY OF ENERGY CONSUMPTION AND "HEAT UP" TIME FOR TEMPERATURE INTERVAL 10°C TO 60°C*

System	Time To Achieve 60°C Average Water Tank Temperature	Energy Consumed Over Period
	Minutes	kWh
A	200	4.25
B	410	6.54
C	330	5.40
D	285	4.18
B'	222	3.54
EWH	170	10.39

* Refer To Figure B3

TABLE B6

ADDITIONAL TEST (ENERGY STAND BY LOSSES)

Storage unit	Capacity	Stand By Losses	
	Litres	Watts	kWh Day
EWH	272	101.3	2.16*
Integral HP-B All Electric Mode	310	166.5	3.56*
Add-On HP Storage Tank	182	115.0	2.46*

*Daily Stand By Losses Are Modified By a Usage Pattern Factor of 0.89 3

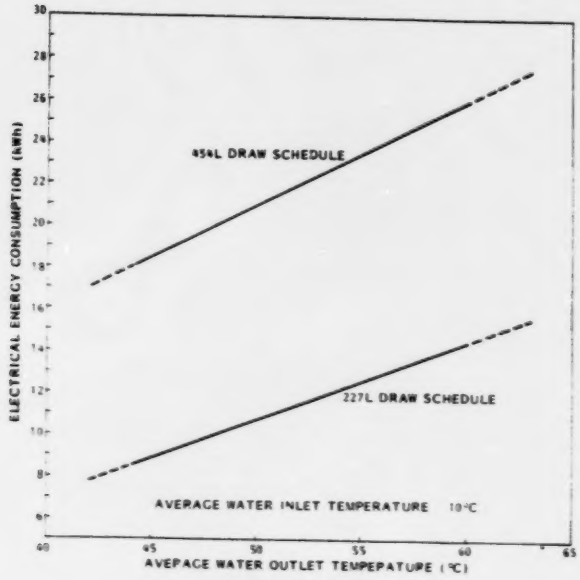
ELECTRICAL ENERGY CONSUMPTION (kWh)
454L DRAW SCHEDULE
227L DRAW SCHEDULE
AVERAGE WATER INLET TEMPERATURE 10°C
AVEPACE WATER OUTLET TEMPEPATURE (°C)

FIGURE B1

ELECTRIC WATER HEATER - RECOVERY EFFICIENCY TEST
TEMPERATURE ADJUSTED ELECTRICAL ENERGY CONSUMPTION
VERSUS AVERAGE WATER OUTLET TEMPERATURE

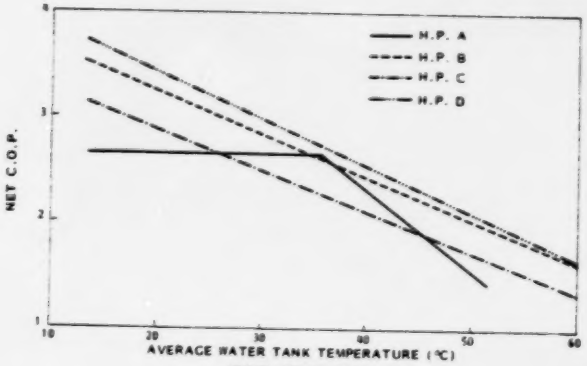

FIGURE B2

RECOVERY EFFICIENCY TEST - NET C.O.P. VERSUS AVERAGE
WATER TANK TEMPERATURE

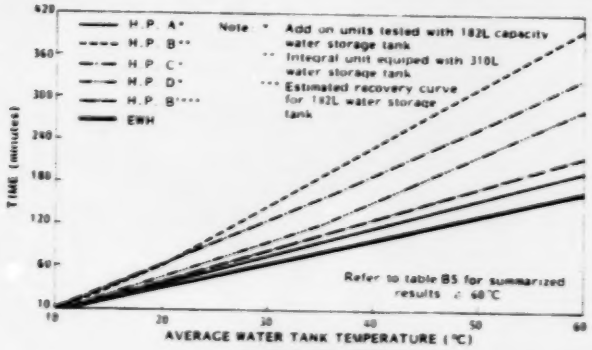
H.P. A*
H.P. B**
H.P. C*
H.P. D*
H.P. B***
EWH
Note: * Add on units tested with 182L capacity water storage tank
** Integral unit equiped with 310L water storage tank
*** Estimated recovery curve for 182L water storage tank
TIME (minutes)
Refer to table B5 for summarized results @ 60°C
AVERAGE WATER TANK TEMPERATURE (°C)

FIGURE B3

RECOVERY EFFICIENCY TEST - HEAT UP TIME VERSUS
AVERAGE WATER TANK TEMPERATURE

APPENDIX C

POTENTIAL BENEFITS FROM INSTALLATION OF HPWH SYSTEMS IN RESIDENCES

HPWHs may provide other benefits in addition to energy savings. Some of these benefits are briefly discussed in this Appendix.

1. Net Yearly Savings of Heat Pump Water Heaters

The extreme winter conditions of the Canadian climate limit the location of a HPWH to either a fully or semi-conditioned space. Although the water heating energy costs are greatly reduced there is an added load on the house heating requirement. Table C1 shows comparative figures on the expected savings achievable for both average and heavy use of hot water in either gas, oil or electrically heated houses ($19 - $76/year). The greatest savings were estimated for gas heated houses. This can be explained by changing the operational mode of the EWH (all electric mode) by a hypothetical partial electric/partial gas water heater due to the installation of the HPWH.

2. Indoor Dryer Venting Heat Recovery

Since most of the energy transferred by the heat pump to the water is extracted from the conditioned space, particular attention must be paid to recovering any form of "waste heat" within the thermal envelope of the house. Indoor dryer venting is one particular method of supplying up to about 50% of the ambient energy requirement for the HPWH. Although this particular form of waste heat is primarily a latent form of heat, the de-humidifying effect of the HPWH should eliminate any non-desirable effects. Table C1 (column 13) presents the effect of this type of heat recovery on the possible savings. The estimated savings with HPWH and dryer heat recovery were in a range of $54 to $102/year. (See detailed assumptions and calculations in Table C1.)

3. Exhaust Air Heat Recovery

Possibly the greatest potential for waste heat recovery available to the HPWH resides in the current trend towards "energy efficient" homes. Many of these homes are believed to require mechanical exhausting of the used air and mechanical induction of fresh air. It may be advantageous to use a HPWH to recover heat from the exhausted air rather than an air-to-air heat exchanger as is the present solution. Further work in this application is required.

4. Shared Gas-Heat Pump Water Heating

There are many homes that already use natural gas for domestic hot water needs. Table C2 presents projected savings for the replacement of the existing gas burner in the water tank by a HPWH system. In this case the water tank will be used as a storage tank for the HP unit. The savings produced by such a scheme are very small even when indoor dryer venting is considered. Another problem with this type of a retrofit is the small capacity tank (150 L as opposed to 182 or 272 L) which will not provide enough stored hot water for heavier users. Thus it appears that such conversions are unattractive.

5. Indoor Air Dehumidification

The HPWH will provide dehumidification which is desirable in all houses in the summertime and in "tighter" houses in the winter. The value of this feature should be answered in more detail in further studies.

TABLE C1

ENERGY AND COST ANALYSIS OF HEAT PUMP WATER HEATERS

1	2	3	4	5	6	7	8	9	10			11			12			13		
Daily Hot Water Usage	Yearly Elec Energy Consumption For a Typical Electric Water Heater	Yearly Cost For Water Heating By Electricity	Yearly Heat Pump Energy Consump (Elec.)	Yearly Savings Of Heat Pump Over Typical Electric Water Heater	Yearly Ambient Energy Required For Heat Pump Operation	Typical Heating Load For Ontario Home	Ambient Heating Load for Heating Season To Run Heat Pump	% Increase In Heating Load Caused By Heat Pump	Home Heating Costs Based on 22,000 kWh Heating Load			Increase in Home Heating Cost for Added Ambient Load Caused by Operation of Heat Pump			Net Yearly Savings of Using Heat Pump Water Heaters			Net Yearly Savings of Using Heat Pump Water Heater When Using Waste Heat from Indoor Dryer Venting		
									Oil	Elec	Gas	Oil	Elec	Gas	Oil	Elec	Gas	Oil	Elec	Gas
Litres (gal)	kWh	$	kWh	$	kWh	kWh	kWh	%	$			$			$			$		
227(50)	5300	212	3100	88	2200	22000	1500	7	1013	880	773	69	60	53	19	28	35	54	58	62
454(100)	9500	380	4750	190	4750		3250	15				150	130	114	40	60	76	75	90	102

ASSUMPTIONS AND CALCULATIONS FOR EACH TABLE COLUMN

1 : 227L/Day Considered Average 454L/Day Considered Heavy Use
2 : Based On Daily Energy Consumption of 14.5 and 26 kWh For 227 And 454 Litres Daily Hot Water Usage
3 : Based On End Rate Of 4¢/kWh
4 : Average Values Of 4 Heat Pumps For Each Draw Schedule With Average Outlet Temperatures of 60°C
5 : 3 (4 x 0.04)
6 : 2 4
7 : Reference /4
8 : Based On Heating Season Of 250 Days With Ambient Requirement of 6 kWh/Day and 13 kWh/Day For 227 and 454 Litres Daily Hot Water Usage Respectively
9 : 8 : 7
10 : Based On Energy Prices Of: Oil @ 30¢/L Furnace Efficiency 60%
Elec @ 4¢/kWh Furnace Efficiency 100%
Gas @ 20¢/m^3 Furnace Efficiency 55%
11 : $8 \times \frac{1}{\text{Furnace Efficiency}} \times$ Cost/Unit Energy
12 : 5 - 11 For Various Energy Types and Usage
13 : 5 - [11 - Dryer Contribution]: Where Dryer Contribution is Taken as 3kW (Assuming 60% Eff; Rating = 5kW) Operating Once Per Day (1 hr On The Average) During the Heating Season

TABLE C2

ENERGY AND COST ANALYSIS OF SHARED GAS - HEAT PUMP WATER HEATING GAS HEATED HOMES

1	2	3		4	5	6	7	8		9	10
Daily Hot Water Usage	Yearly Electrical Energy Consump. for a typical Electric Water Heater	Yearly Gas Consumption of Typical Gas Water Heater		Yearly Cost of Hot Water Heating by Gas	Yearly Cost of Hot Water Heating by Electricity	Yearly Ambient Load Caused By Heat Pump	Yearly Cost of Electricity for Heat Pump	Increase in Home Heating Cost for Added Ambient Load By Heat Pump (Gas Cost)		Net Yearly Savings Using Heat Pump In Place of Gas Water Heater	Net Yearly Savings Using HP in Place Of Gas Water Heater In Homes With Waste Heat Recovery From Indoor Dryer Venting
Litres(gal)	kWh	kWh	M^3	$	$	kWh	$	kWh	$	$	$
227(50)	5300	9624	930	186	212	2190	124	1500	53	9	36
454(100)	9500	17255	1667	334	380	4745	190	3250	114	30	56

Assumptions and calculations for each table column

1. 227L/Day considered average, 454L/Day considered heavy use
2. Based on daily energy consumption of 14.5 and 26 kWh for 227 and 454 Litres Daily Hot Water usage respectively
3. Gas consumptin based on gas hot water tank efficiency of 55% and 1 m^3 of gas 35318 BTU
4. Based on cost of 20¢/m^3
5. Based on 4¢/kWh
6. Based on daily HP ambient energy requirement of 6kWh and 13 kWh for 227L and 454L daily hot water usage respectively
7. Based on 4¢/kWh
8. Based on heating season of 250 days with daily ambient requirement as stated in 6 and furance efficiency of 55% gas cost; 20¢/m^3
9. 4 [7 - 8]
10. Based on dryer contribution of 3 kW(assuming 60% eff.; rating 5 kW) operating once per day (1 hr on the average) during the heating season

APPENDIX D

TECHNICAL SPECIFICATIONS OF SOME OF THE COMMERCIALLY AVAILABLE HPWH

TECHNICAL SPECIFICATIONS OF SOME OF THE COMMERCIALLY AVAILABLE HPWH SYSTEMS

Heat Pump Water Heater Unit			1	2	3	4	5	6	7	8
Heat Pump Type			Add on	Add on	Add on	Integral	Add on	Add on	Add on	Add on
Cuefficient of Performance (C.O.P.)			3.68	2.8	2.54	2.0	2.82	1.84	2.5	2.8
Ambient Conditions For C.O.P.	D.B.	°C(°F)	27 (80.6)	26.7(80)	23.9(75)	23.9 (75)	26.7 (80)	23.9(75)	26.7(80)	23.9(75)
	R.H.	%	50	50	53	50	40	50	50	50
Ambient Operating Temperatures	max	°C(°F)	30(86)	43(110)	35-46(95-115)	38-43(100-110)	38-43 (100 110)	46(115)	38(100)	43(110)
	min	°C(°F)	5(41)	13(55)	7-10(45-50)	4-7 (40-45)	4-7(40-45)	7(45)	13(55)	7(45)
Heat Pump Capacity	Heating	kW(BTUH)	2.3 (7850)	2.20 (7500)	3.52 (12000)	2.05 (7000)	n.a.	3.52(12000)	2.4(8200)	2.8(9550)
	Cooling	kW(BTUH)	n.a.	1.83 (6250)	2.23 (7600)	1.76 (6000)	n.a.	n.a.	1.76(6000)	n.a.
	Conditions For Heat Pump Capacity		Ambient Conditions and 10°C (50°F) Water Inlet Temp	Ambient Conditions and 57°C (135°F) hot water tank temp	Ambient Conditions	Ambient Conditions and 13°C(55°F) water inlet with 49°C(120°F) water outlet temp	n.a.	Ambient Conditions	Ambient Conditions	Ambient Conditions
Recovery Rate Of Heat Pump	L / hr		57.13	56.75	68.10	75.67	70.00	45.02	47.67	*
	Conditions For Recovery Rate		Ambient Conditions And A 42°C (108°F) Temp Rise of Water	Ambient Conditions	Ambient Conditions And Inlet Water At 12.8°C (55°F)	Ambient Conditions And 12.8°C (55°F) Inlet Water Temp With Avg Tank Temp of 57°C(135°F)	Ambient Conditions with 13°C(55°F) Water Inlet Temperature	Ambient Conditions	Ambient Conditions	Ambient Conditions with 10°C(50°F)water inlet and 50°C (90°F) Temperature rise
Maximum Hot Water Delivery Temperature		°C(°F)	55(130)	60(140)	60(140)	60(140)	60(140)	60(140)	38-57(100-135)	60(140)
Electrical Supply	Voltage	V	115	115	230	220	115	115	115	115
	Current	A	6.6	11.2	15	30	13.3	16	11.6	12
Circulating Water Pump Flow Rate		L/min	2.65	7.57	1.14-6.05	Not Applicable	8.12	n.a.	11.35	13.24
Refrigerant Type			R 22	R 500	R 22	R 12	R 12	R 12	R 22	R 12
Thermostatic Control And Location			Linked with existing thermostat in hot water storage tank	Variable thermostat located on heat pump control panel	24V thermostat replaces hot water storage tank thermostat	Variable upper and lower thermostat which controls heat pump and upper element	Internal heat pump sensor switches heat pump "on" when water temperature falls below 49°C (120°F)	Linked with existing thermostat in hot water storage tank	Variable thermostat located on heat pump	Linked with existing tank thermostat. Heat pump is activated when tank temp falls 6°C(10°F) below desired setting
Comments			Temperature, pressure and freeze protection provided. With protection controls "off" hot water is available at 70°C (158°F)	On/off feature for tank elements on heat pump control panel. Contoured casing to fit beside hot water tank and minimize space requirement	Variable flow controlled by thermostatic modulating valve which maintains water outlet of heat pump at 46°C (115°F)	Condenser leak protection, 310L storage tank with 2 x 2500W heating elements. Upper element helps in recovery situation. Lower element is for resistance heating only	Water temperature sampling every 10min to assure proper tank temperature. De liming provision. Quick connect poly butylene tubing.	Frost protection device that switches back to hot water tank elements. Thermostatic flow control value can also be wired for 240V, 15A receptacle	Cool air discharge can be ducted. Dual air blowers for intake and exhaust. Built in timer samples for 3.5 min at 15 min intervals	Control module monitors water to determine on/off operation of heat pump. "Co axial" flow configuration warms incoming cold water before entering pump

1: HP D
2: HP C
3: HP A
4: HP B

n.a.: Not Available

* 1°F/min at Given Conditions

POOR

QUALITY

ORIGINAL